Radiometric Calibration Validation of Satellite Sensor Systems

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Satellite Calibration Group and
Image Processing Lab

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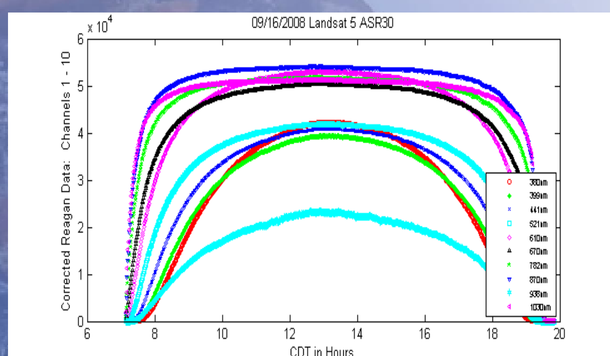


JACIE: Fair Oaks April 1, 2009

Satellite Calibration Discussion:
Primarily Landsat System based

What does Landsat have to do with commercial remote sensing activities?

1. Landsat is the ‘gold standard’

   “Stable, reliable, workhorse”

2. Landsat data provides the long term traceable data record for satellite sensor systems: 1972 through 2009 and counting.

Satellite Calibration Activities

Three areas discussed:

I. Continuing Vicarious Calibration Activities

Landsat 5 and 7

II. ‘Back Calibration’ Issues

MSS through ETM+

SBAF (spectral band adjustment factor)

III. First order atmospheric correction activities

Outline of the vicarious calibration process (Reflectance based method)

- ‘Simultaneous’ satellite imaging and hyperspectral measurement of upwelling radiance at grass target area (“3M” in Brookings SD).

- Monitor atmospheric transmittance over time interval including overpass (10 Channel ASR unit 30)

- Use ASR Langley analysis to model atmosphere
  - previously using MODTRAN 4.3.2
  - SDSU a beta tester for MODTRAN 5 but results presented are from 4.3

- Transfer ‘up’ ground level radiances to TOA using MODTRAN model

- Band hyperspectral TOA radiances to produce in-band TOA radiance

- Calculate gain by comparing measured satellite DN values to in-band TOA radiance values

“3M” Site Characteristics

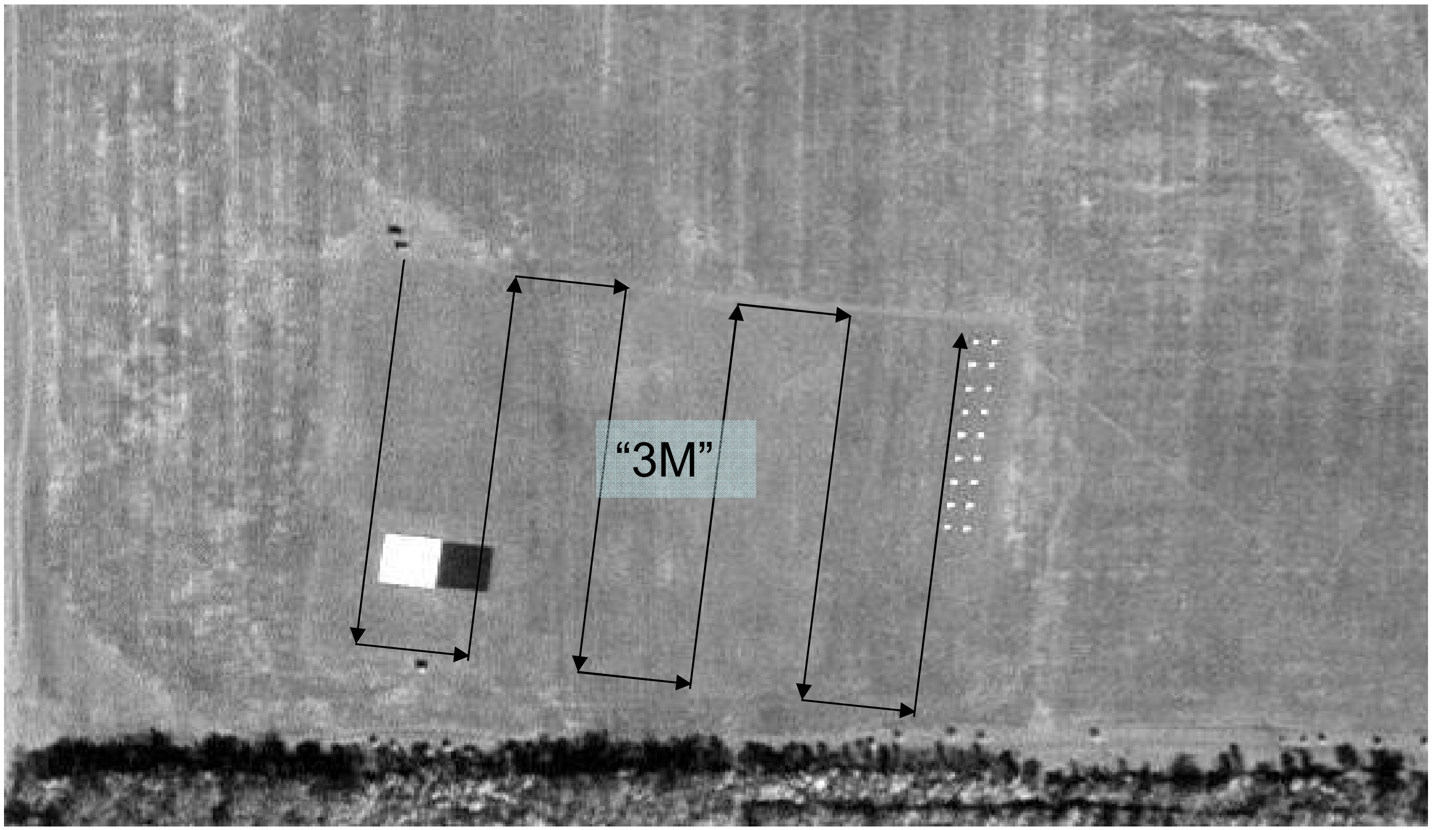
- 200m X 180m ‘grass’ site (approx)
  - rotated 6 degrees off N-S
  - NW corner:
    - Lat: 44°17'31.12383"N
    - Long: 96°45'59.33636"W
  - Maximum measured elevation change = 4.89 meters

    Differential GPS values measured by the Stennis GRIT Staff

Maintenance Primarily mowing

- 6 ft rotary mower results in fairly long (~10cm) height grass.
- mowed at ~3 week intervals

Data Collection Paths for “3M” part of site
Oct 7,2005 (Orbview)

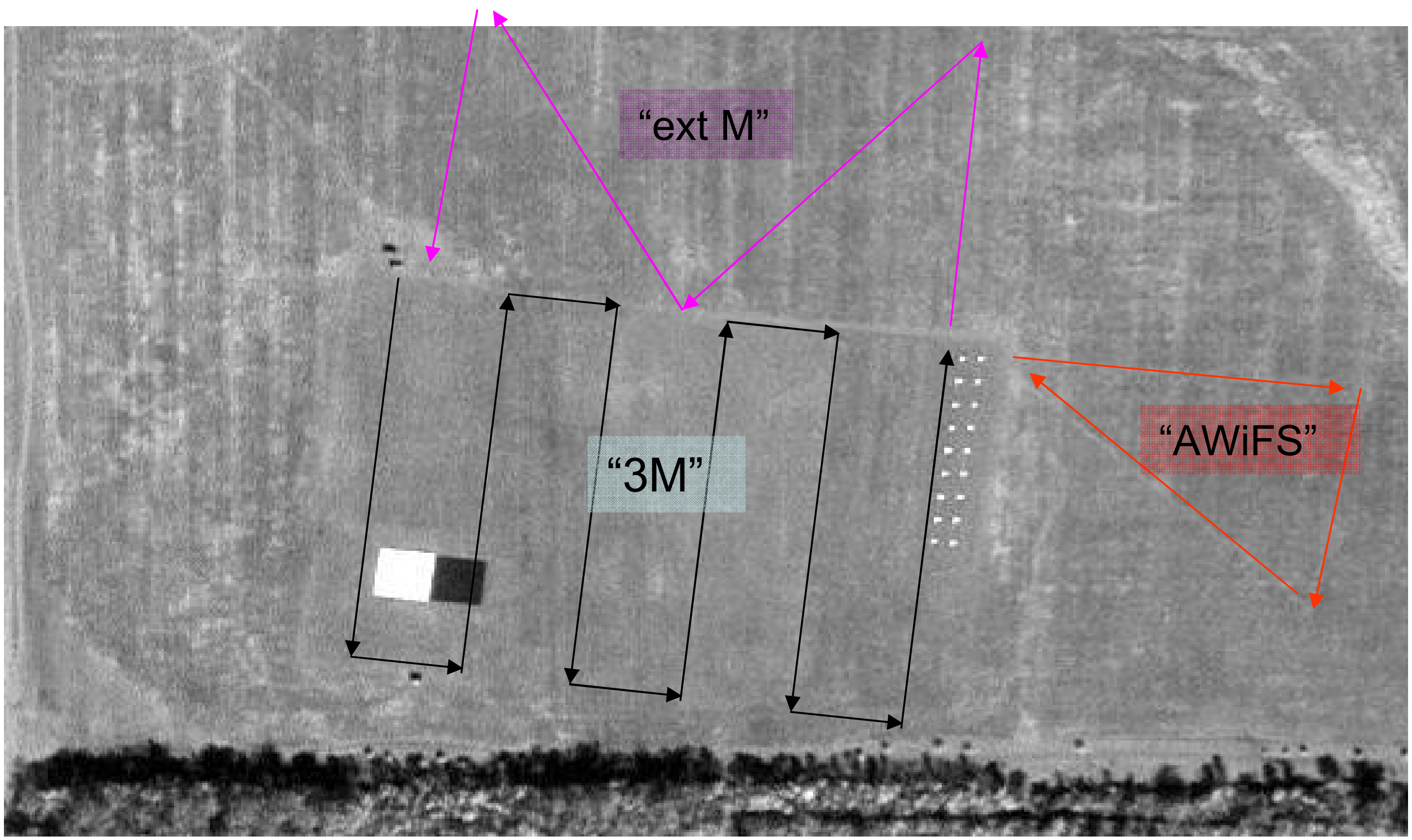


Data Collection Area Extensions

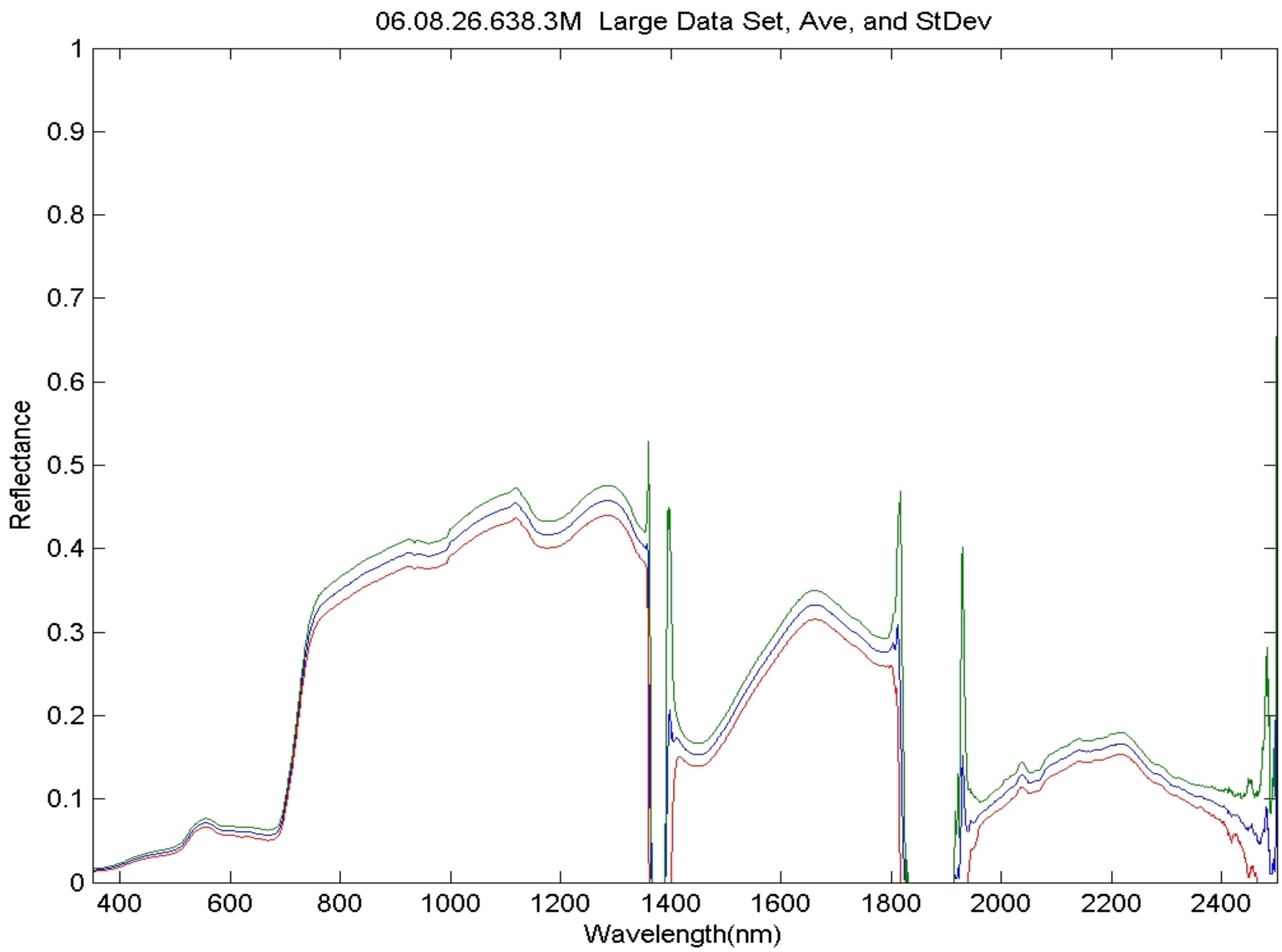
Beginning in 2005, extensions were made to the collection paths

- To support AWIFS validation in cooperation with SSC added the “AWIFS triangle” just east of main site
- For several 2007-8 collections, also performed ground measurements North of main site: “ext M”
  - Area is periodically ‘hayed’, so is useable for a few weeks after haying operation.
  - Hayed area has slightly different spectral and BRDF characteristics so it treated as a separate target
- We have analyzed, but I have not included those points in this particular report.

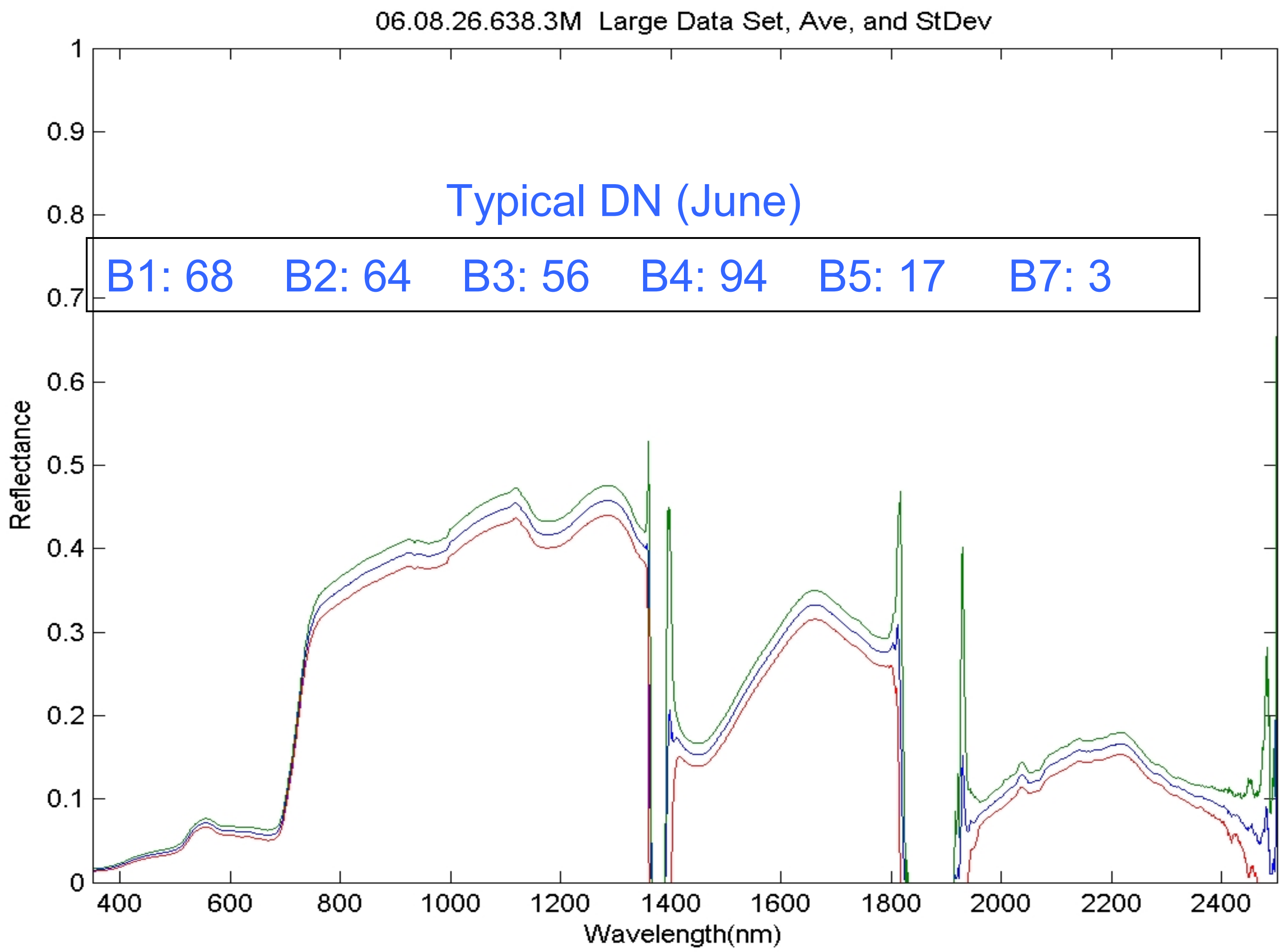
Site with “AWIFS” and “ext M” shown
Oct 7,2005 (Orbview)



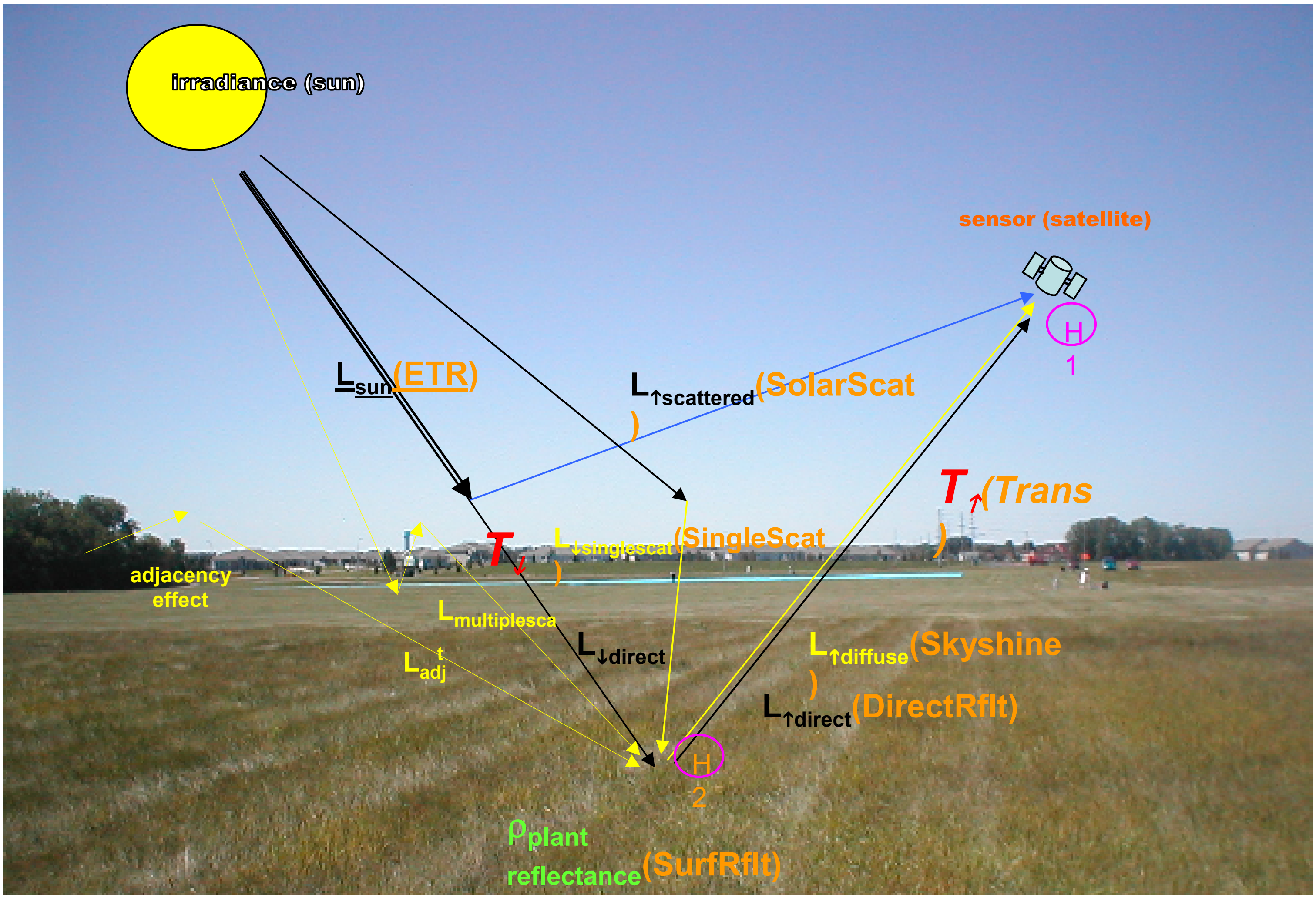
Typical Site Reflectance
SDSU Grass Site



Adding in typical DN values for 3M site (note low values in bands 5 & 7)



Radiance Paths for MODTRAN analysis



2007 Data Collections:

The SDSU group is prepared to deploy for every overpass from mid-May through fall (weather cut-off)

Some years the sky is just a bit uncooperative.

17-May	Landsat 7	clouds
25-May	Landsat 5	clouds
2-Jun	Landsat 7	clouds
10-Jun	Landsat 5	clouds
18-Jun	Landsat 7	clouds
26-Jun	Landsat 5	rain
4-Jul	Landsat 7	good- (hazy)
12-Jul	Landsat 5	clouds
20-Jul	Landsat 7	good– (popcorn)
28-Jul	Landsat 5	clouds
5-Aug	Landsat 7	clouds
13-Aug	Landsat 5	fair– (cirrus)
21-Aug	Landsat 7	clouds
29-Aug	Landsat 5	fair– (cirrus)
6-Sept	Landsat 7	clouds
14-Sept	Landsat 5	clouds
22-Sept	Landsat 7	clouds
29-Sept	Renville, MN	good
30-Sept	Landsat 5	clouds
8-Oct	Landsat 7	clouds
16-Oct	Landsat 5	Bat 2
24-Oct	Landsat 7	good

Other years (like 2008)?

"…

Ev'ry day was a cloudy day for me
Then good luck came a-knocking at my door
Skies were gray but they're not gray anymore

Blue skies
Smiling at me
Nothing but blue skies
Do I see"

Irving Berlin (1926)

popularized later by Bing Crosby

2008 Data Collections

Well, maybe not "nothing but blue skies", but I love 'EXCELLENTS'

19-May	Landsat 7	clouds
27-May	Landsat 5	clouds
4-Jun	Landsat 7	clouds
12-Jun	Landsat 5	EXCELLENT
20-Jun	Landsat 7	fair + (some cirrus)
28Jun	Landsat 5	clouds
6-Jul	Landsat 7	clouds
14-Jul	Landsat 5	good
22-Jul	Landsat 7	good– (popcorn)
30-Jul	Landsat 5	clouds at overpass
7-Aug	Landsat 7	good
15-Aug	Landsat 5	fair
23-Aug	Landsat 7	good – (haze)
31-Aug	Landsat 5	holiday
8-Sept	Landsat 7	fair
16-Sept	Landsat 5	EXCELLENT
24-Sept	Landsat 7	marginal (major cirrus)
2-Oct	Landsat 5	Good +
18-Oct	Landsat 7	clouds all a.m.
26-Oct	Landsat 5	Clouds
3-Nov	Landsat 7	Clouds

Landsat 7

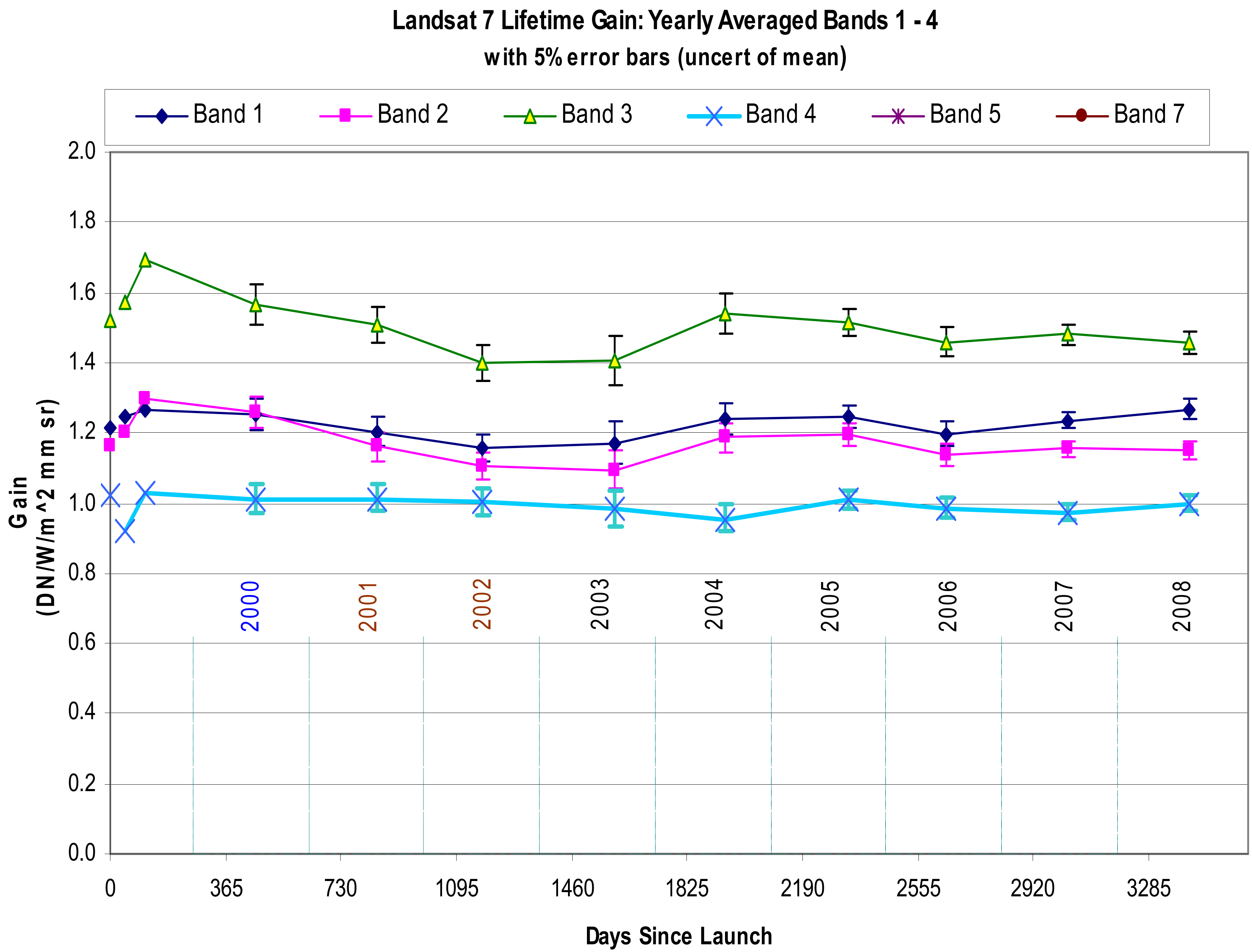
- The group has generally had ‘reasonable’ luck with Landsat 7.
  - 2006: ‘2 goods’, ‘fair’
  - 2007: ‘good’, 3 ‘fairs’
  - 2008: ‘2 goods’, ‘2 fairs’, and a ‘marginal’

- 2008 was better than usual for L7

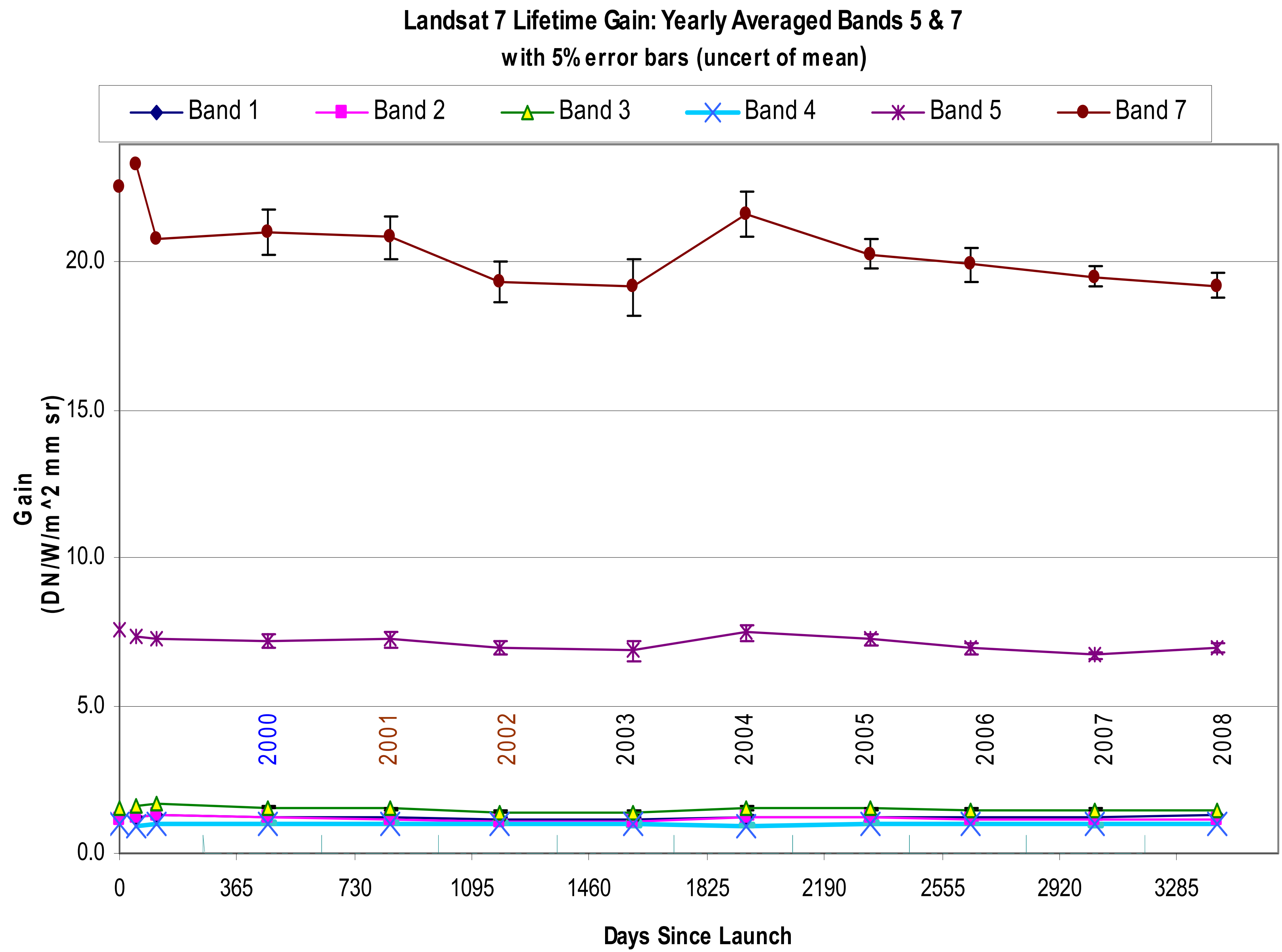
Landsat 7: 2008 Data Points SDSU

*Band 4 normalized to low gain

Date		DSL	Band 1 (m² µm sr)/W DN/Rad	Band 2 (m² µm sr)/W DN/Rad	Band 3 (m² µm sr)/W DN/Rad	Band 4* (m² µm sr)/W DN/Rad	Band 5 (m² µm sr)/W DN/Rad	Band 7 (m² µm sr)/W DN/Rad
20-Jun	fair+	3355	1.276	1.160	1.584	1.468	7.056	20.016
7-Aug	good	3403	1.273	1.130	1.333	1.523	6.781	17.433
23-Aug	good-	3419	1.242	1.154	1.433	1.515	7.143	19.414
8-Sep	fair	3435	1.346	1.205	1.551	1.574	7.433	21.187
24-Sep	marginal	3451	1.192	1.087	1.377	1.417	6.260	18.042
stdev			0.056	0.043	0.109	0.059	0.443	1.510
			4.4%	3.8%	7.5%	4.0%	6.34%	7.9%



Landsat 7 Lifetime Gain: Yearly Averaged Bands 1 - 4
with 5% error bars (uncert of mean)
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7
Gain
(DN/W/m^2 mm sr)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
0
365
730
1095
1460
1825
2190
2555
2920
3285
Days Since Launch



Landsat 7 Lifetime Gain: Yearly Averaged Bands 5 & 7
with 5% error bars (uncert of mean)
Band 1
Band 2
Band 3
Band 4
Band 5
Band 7
Gain (DN/W/m^2 mm sr)
20.0
15.0
10.0
5.0
0.0
2000
2001
2002
2003
2004
2005
2006
2007
2008
0
365
730
1095
1460
1825
2190
2555
2920
3285
Days Since Launch

Results?

- Landsat 7 remains a very stable platform. The calibration factors in the existing CPF remain viable. There may be a slight gain degradation but nothing yet of significance at the 0.01 level.

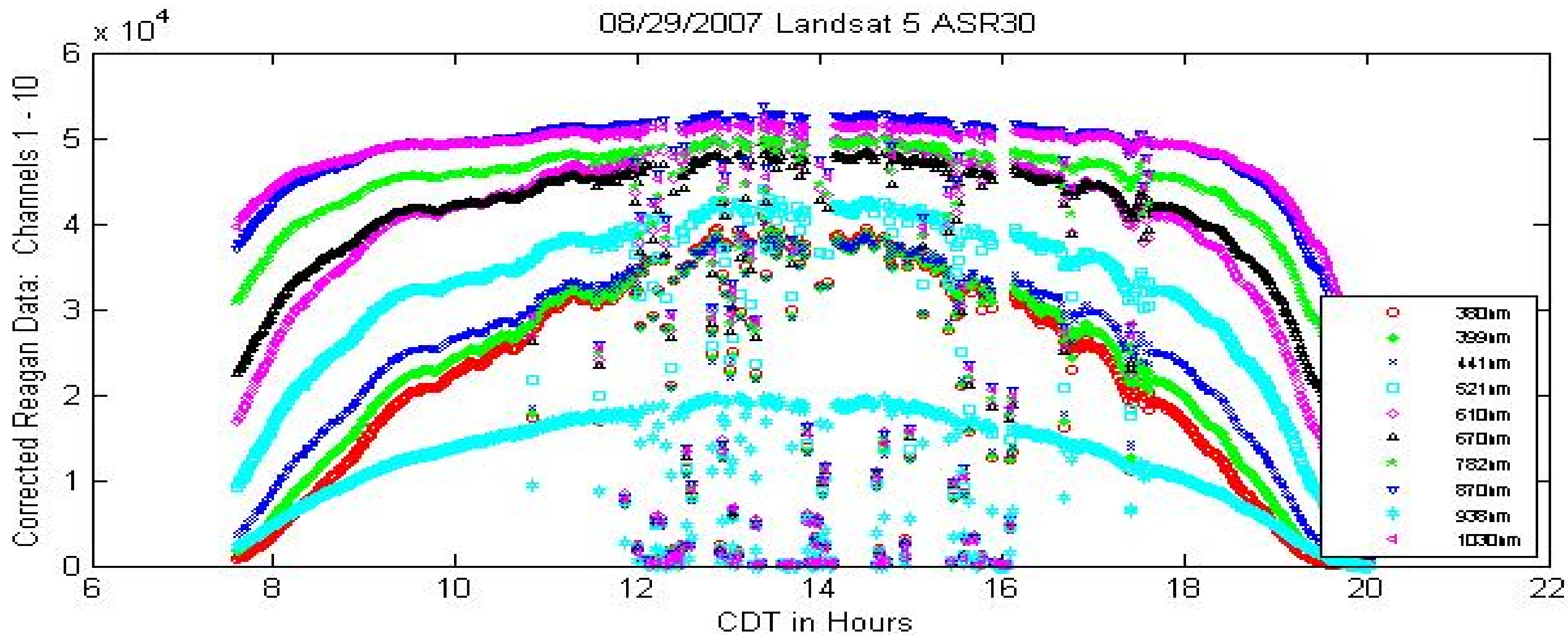
A great deal of work for nothing? The user community can be the ultimate judge but we feel that sometimes observing and validating ‘no change’ is the best possible result.

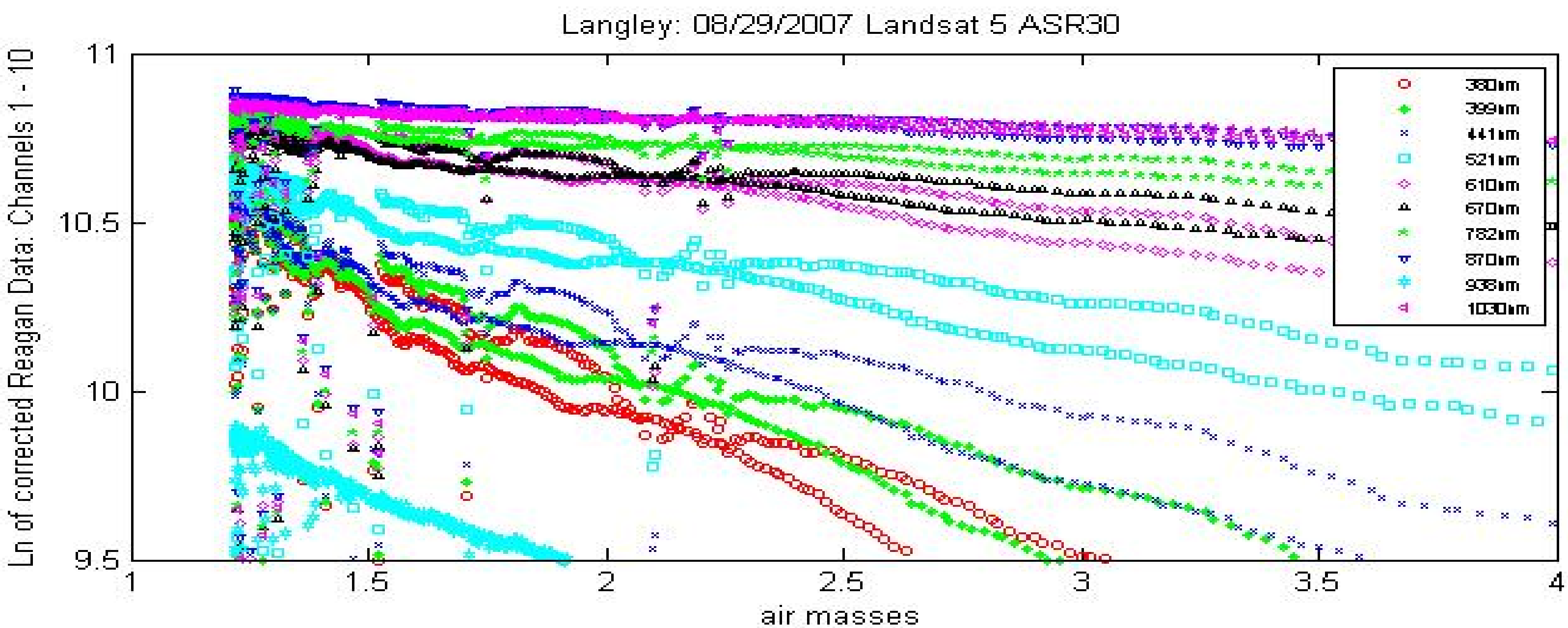
And what of Landsat 5? Remember those grey skies of 2007?

Landsat 5: 2007 Data Points SDSU

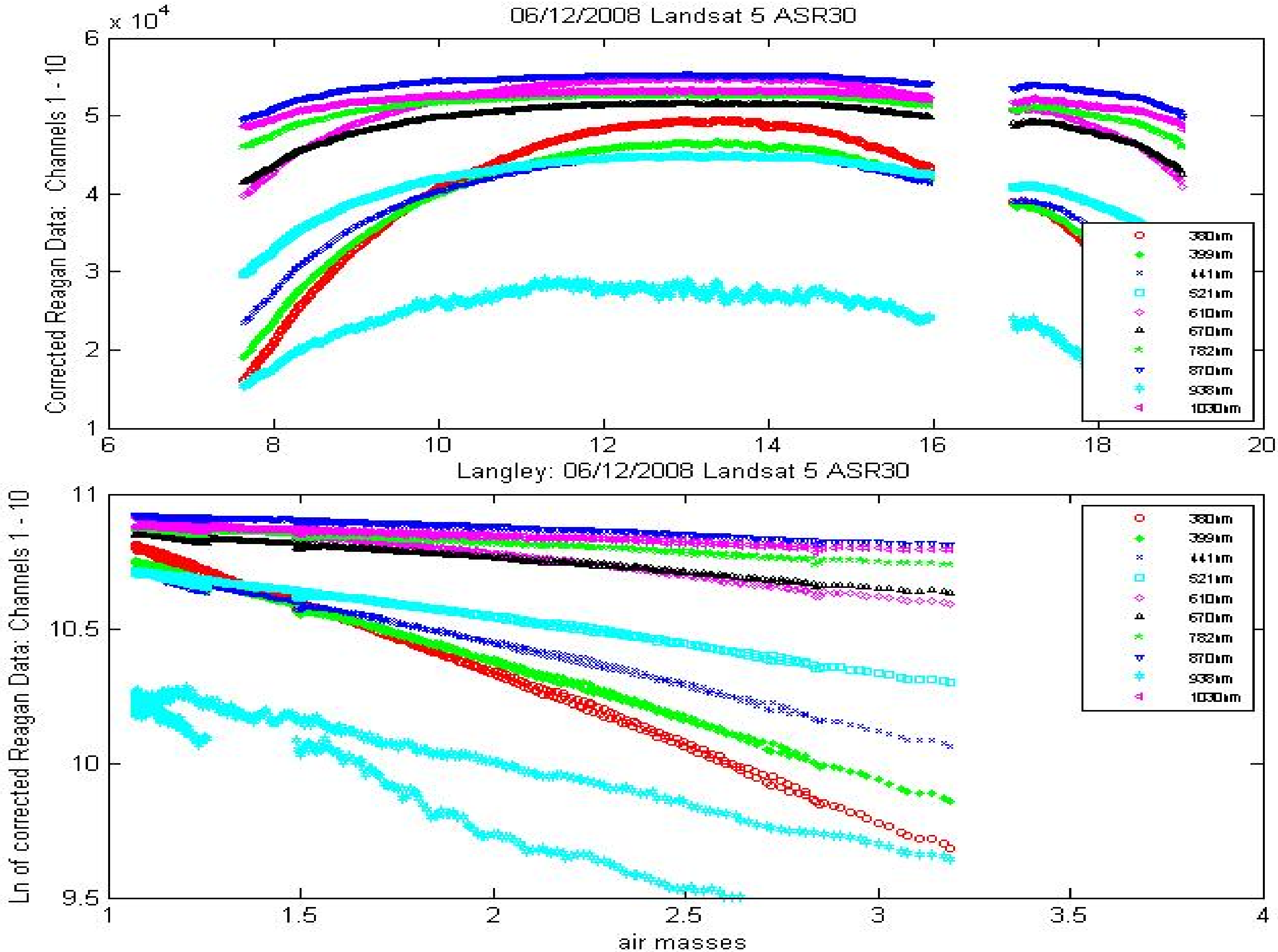
Both dates use extended site
Considerable cirrus both days

Date		DSL	Band 1 (m² µm sr)/W DN/Rad	Band 2 (m² µm sr)/W DN/Rad	Band 3 (m² µm sr)/W DN/Rad	Band 4* (m² µm sr)/W DN/Rad	Band 5 (m² µm sr)/W DN/Rad	Band 7 (m² µm sr)/W DN/Rad
13-Aug	**fair-**	**8566**	**1.322**	**0.704**	**0.962**	**1.137**	**7.732**	**15.430**
29-Aug	**fair-**	**8582**	**1.438**	**0.726**	**0.998**	**1.144**	**7.793**	**14.853**

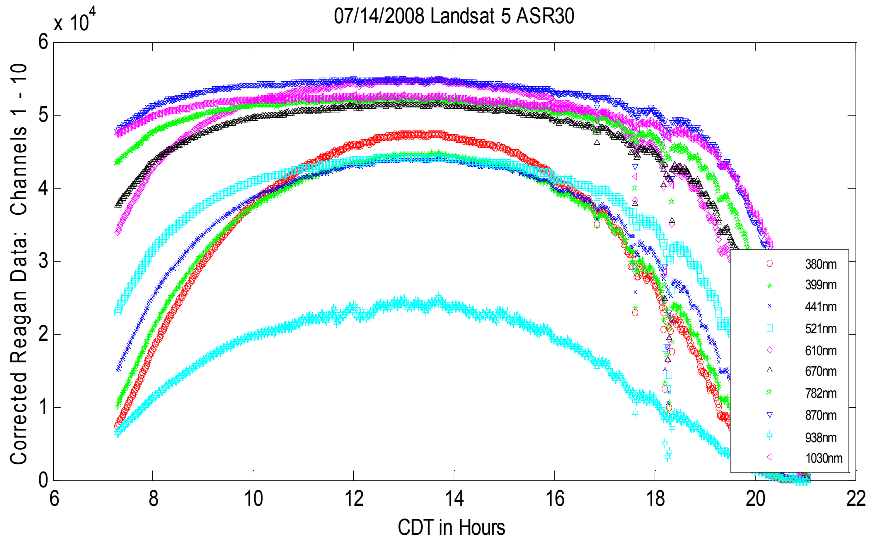

08/29/2007 Landsat 5 ASR30
x 10^4
Corrected Reagan Data: Channels 1 - 10
CDT in Hours
380nm
399nm
441nm
521nm
610nm
670nm
782nm
870nm
938nm
1030nm


Langley: 08/29/2007 Landsat 5 ASR30
Ln of corrected Reagan Data: Channels 1 - 10
air masses
380nm
399nm
441nm
521nm
610nm
670nm
782nm
870nm
938nm
1030nm

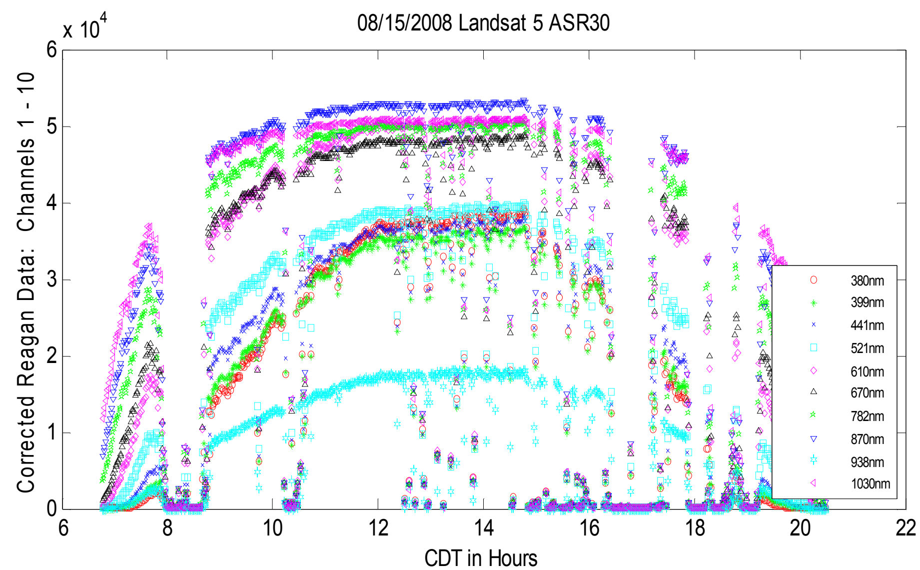
Our first ‘Excellent’ Landsat 5 (June 12, 2008)!



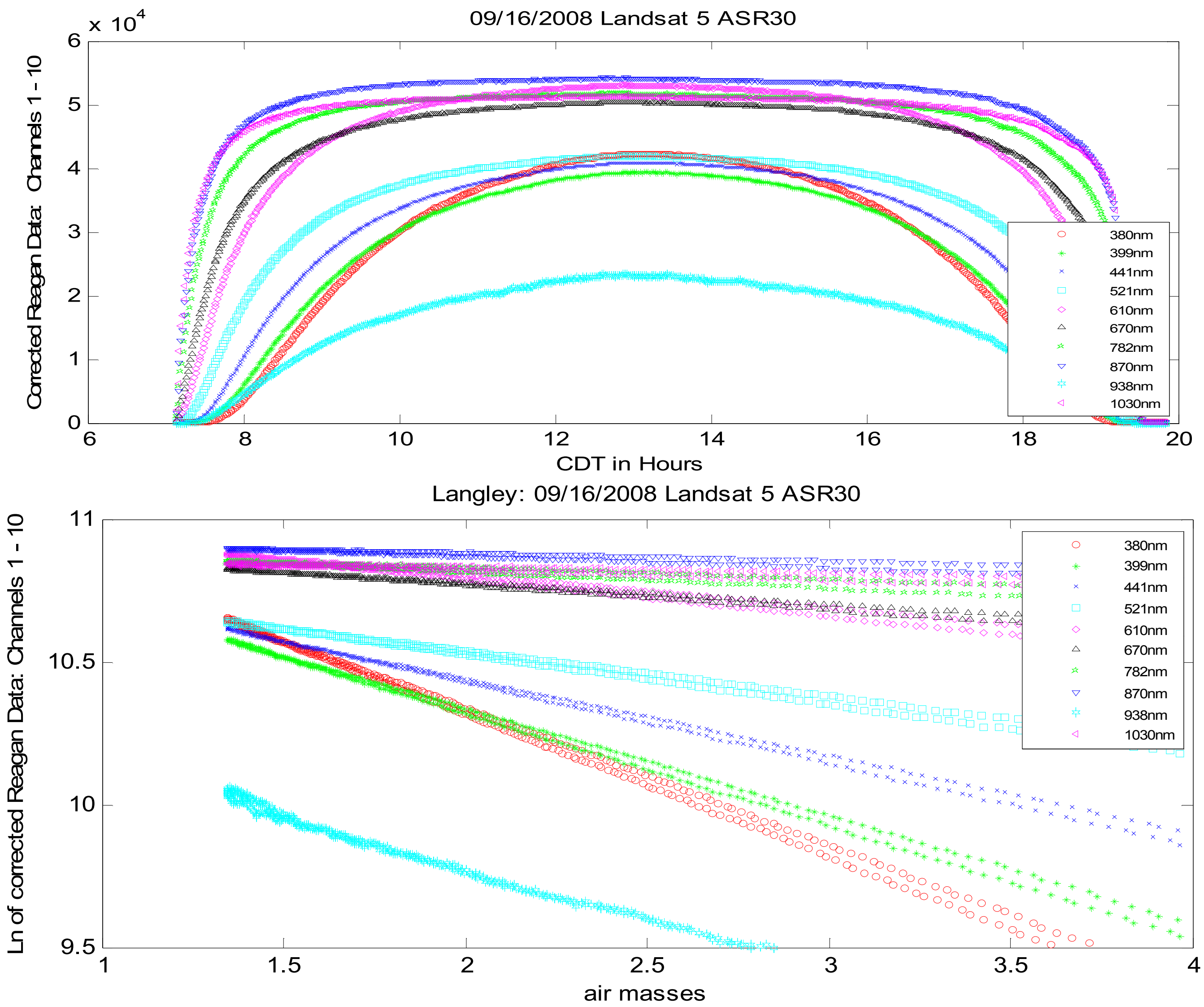
Then a good



and a fair

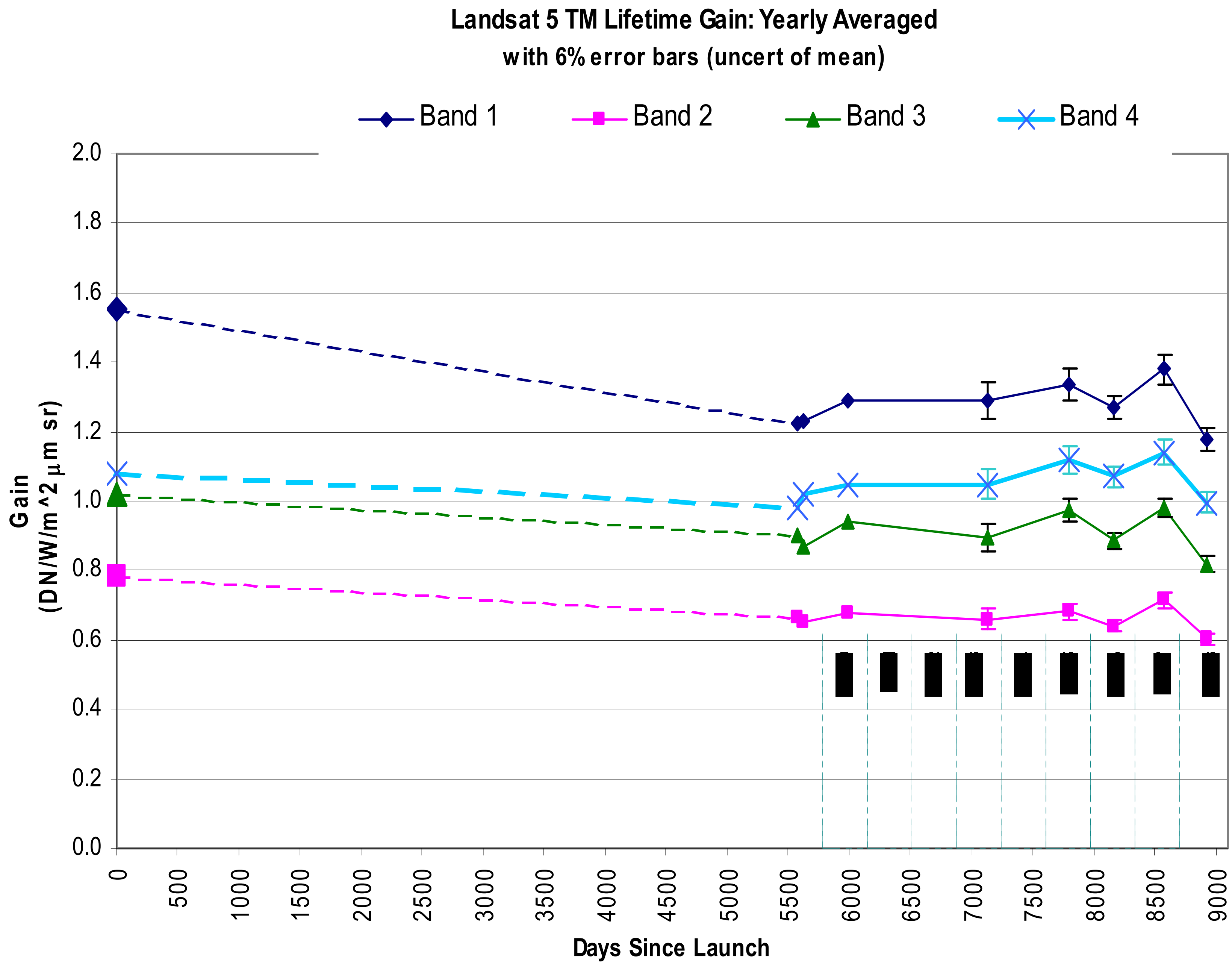


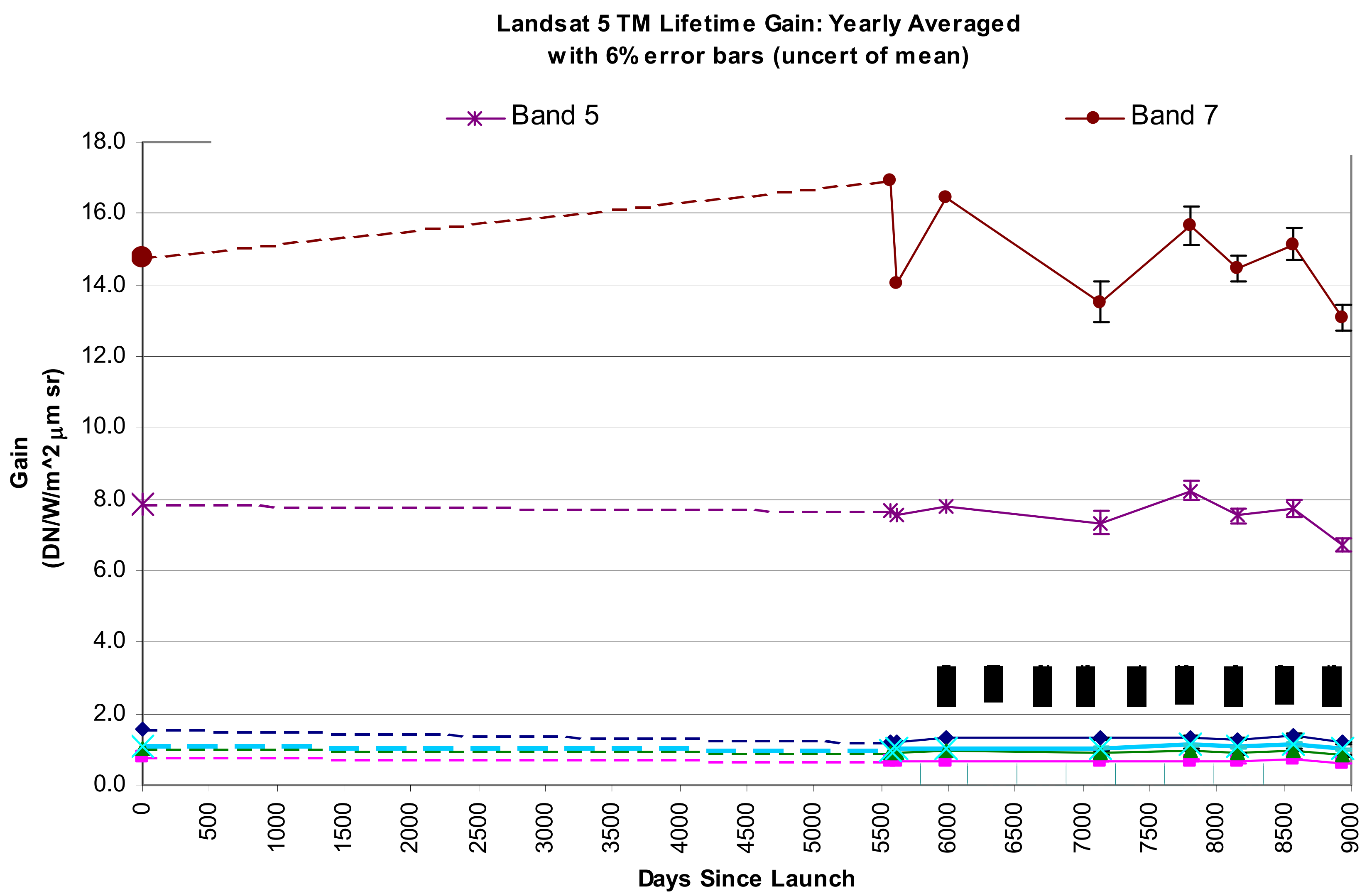
And then amazingly again:



Landsat 5: 2008 Data Points SDSU

Date		DSL	Band 1 (m^2 µm sr)/W DN/Rad	Band 2 (m^2 µm sr)/W DN/Rad	Band 3 (m^2 µm sr)/W DN/Rad	Band 4 (m^2 µm sr)/W DN/Rad	Band 5 (m^2 µm sr)/W DN/Rad	Band 7 (m^2 µm sr)/W DN/Rad
12-Jun	excellent	8870	1.142	0.578	0.807	1.008	7.011	13.23
14-Jul	good	8902	1.221	0.626	0.853	0.987	7.042	14.17
15-Aug	fair	8934	1.189	0.615	0.839	1.055	6.819	12.85
16-Sep	excellent	8966	1.154	0.577	0.800	0.948	6.450	12.64
2-Oct	good	8982	1.179	0.620	0.790	0.983	6.356	12.61
stdev			0.031	0.024	0.027	0.039	0.317	0.646
			2.6%	*4.0%*	*3.3%*	*4.0%*	*4.7%*	*4.9%*


Landsat 5 TM Lifetime Gain: Yearly Averaged
with 6% error bars (uncert of mean)
Band 1
Band 2
Band 3
Band 4
Gain
(DN/W/m^2 µm sr)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
Days Since Launch


Landsat 5 TM Lifetime Gain: Yearly Averaged
with 6% error bars (uncert of mean)
Band 5
Band 7
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Gain
(DN/W/m^2 μm sr)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
Days Since Launch

Conclusions

- Landsat 5 TM continues to maintain a calibration which is stable to within our long term measurement accuracy. Some gain degradation may be occurring, but previous year's acquisitions in only 'fair' weather conditions limit the useful data acquired.
- When the weather cooperates, excellent data can be obtained using the vegetated 3M site. Vicarious calibrations can be made to within a precision of approximately 4% for bands 1-5.

II. 'Back Calibration' Issues

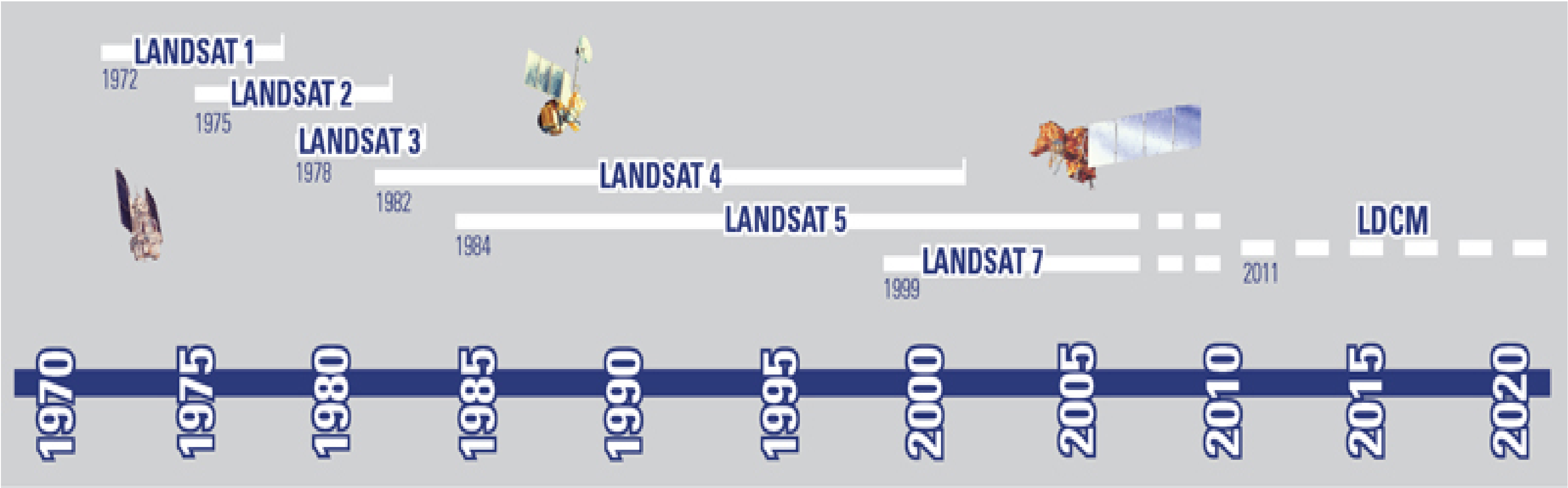
MSS through ETM+

SBAF (spectral band adjustment factor)

Any similarities to D. Helder's "Consistent Calibration of the Landsat MSS Archive" is not accidental (we work with the same graduate students).

Motivation:
Over 35 years of data

Landsat Missions Timeline



Graphic from: landsat.usgs.gov/about_mission_history.php

Landsat Sensor Systems:

A data archive exists from 6 Landsat sensor systems

Sensor systems include:

- Landsats 1-3
  - RBV
  - MSS
- Landsats 4-5
  - MSS
  - TM
- Landsat 7
  - ETM+

With the launch of OLI the long term data base will extend into the future.

SDSU, in concert with USGS and NASA, established a project to establish a means of ‘back calibrating’ Landsat 4 TM and the MSS sensors.

*Goal is to maximize radiometric consistency**

-Find what techniques can be best utilized to produce the appropriate calibrations.

-Provide input to USGS for IAS development (MSIAS).

*Note: project deals with non-thermal bands only

Details:

- Refer to D. Helder’s
- 8:30 a.m. presentation:
  - *Consistent Calibration of the Landsat MSS Archive*

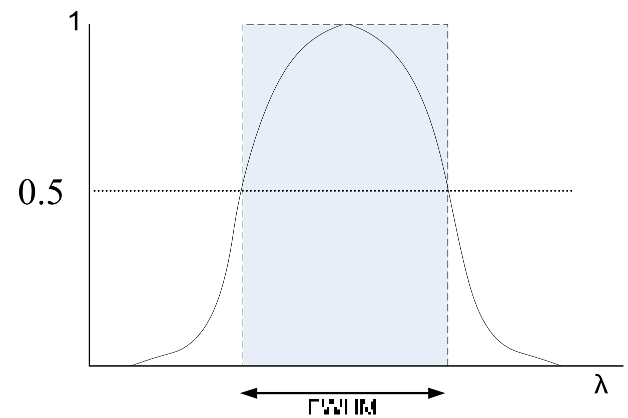
- 3:40 pm
  - *Towards a Worldwide Library of Pseudo-Invariant Radiometric Calibration Sites*

Re-emphasize/Pre-emphasize Two Areas:

- Spectral Band Effects:
- In order to radiometrically compare data from different sensor systems we need ‘apples to apples’.
- 1. Band naming conventions
- 2. Spectral Bandwidths
- 3. Absolute spectral response

Bandwidth considerations for In-band Radiance to Spectral Radiance conversion

- Since sensor passbands are not exactly rectangular, conversion of in-band radiance to spectral radiance always involves some degree of approximation.
- 'Bandwidth' might mean:
  - Nominal BW
  - FWHM (Markham and Barker, 1983)
  - Equivalent Rectangular Bandwidth (ERBW)
  - Quadratic moment BWs (Palmer, 1984; Malila and Anderson, 1986)



Different estimates for effective BWs for L5 MSS bands (in um)

Band	Nominal BW	FWHM BW	ERBW	QMBW
1	0.100	0.109	0.106	0.1162
2	0.100	0.0937	0.089	0.0988
3	0.100	0.1099	0.099	0.1163
4	0.300	0.2263	0.221	0.2752

Key Concern: Dissimilar RSR Profiles

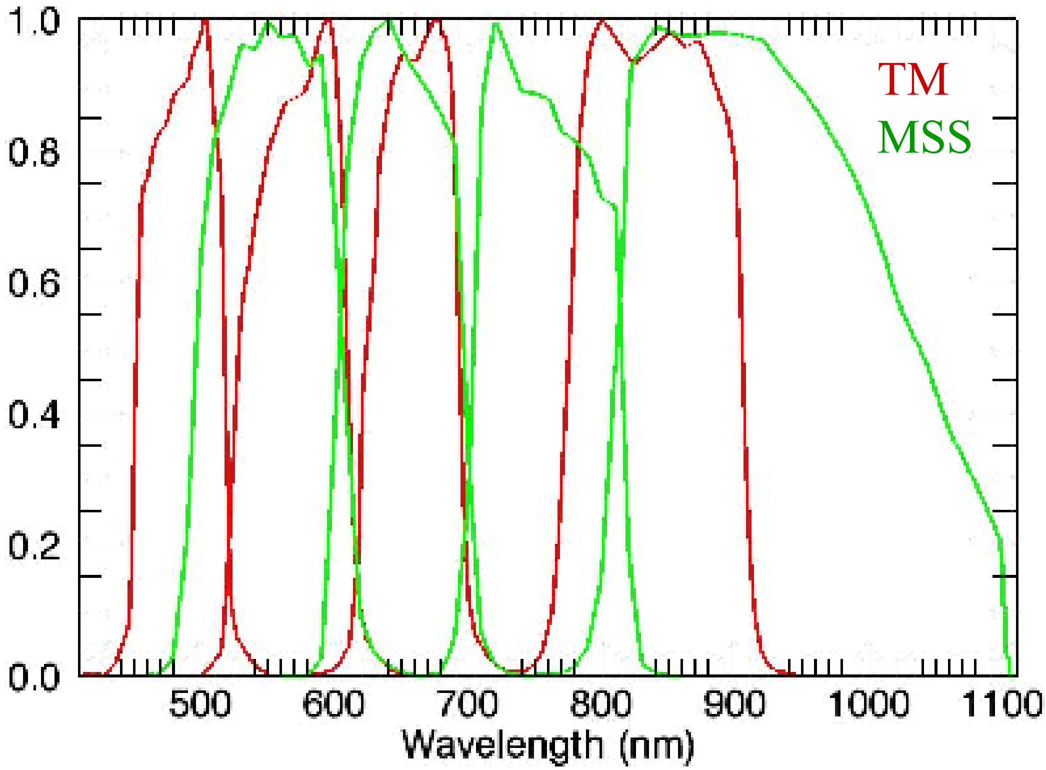
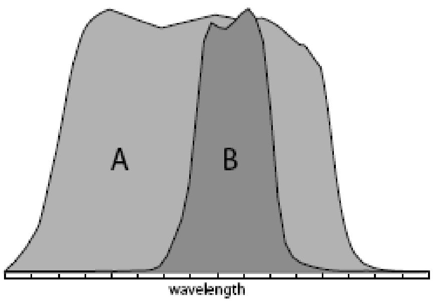


Figure of Merit (FOM, α)

$$\alpha = \frac{A \cap B}{A \cup B}$$



This indicates which bands of two different sensing instruments should respond more similarly to ground targets as compared to others

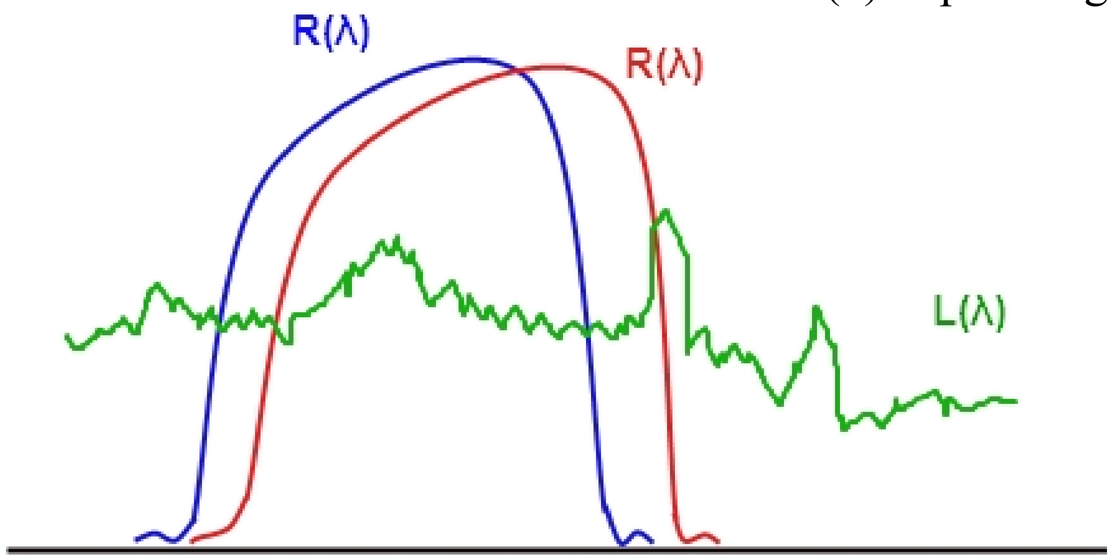
Spectrally best matching pairs

MSS	TM	FOM
B1	B2	0.635
B2	B3	0.708
B3	B4	0.182
B4	B4	0.328

- **None of the four bands match closely in their RSR profiles**, indicating that the two sensors may produce different results while looking at the same ground target
- Effect of Spectral Band Difference is scene specific, and we need to know the spectral signature of target as well to find the Spectral Band Adjustment Factors (SBAFs)

Spectral Band Adjustment Factors (SBAFs)

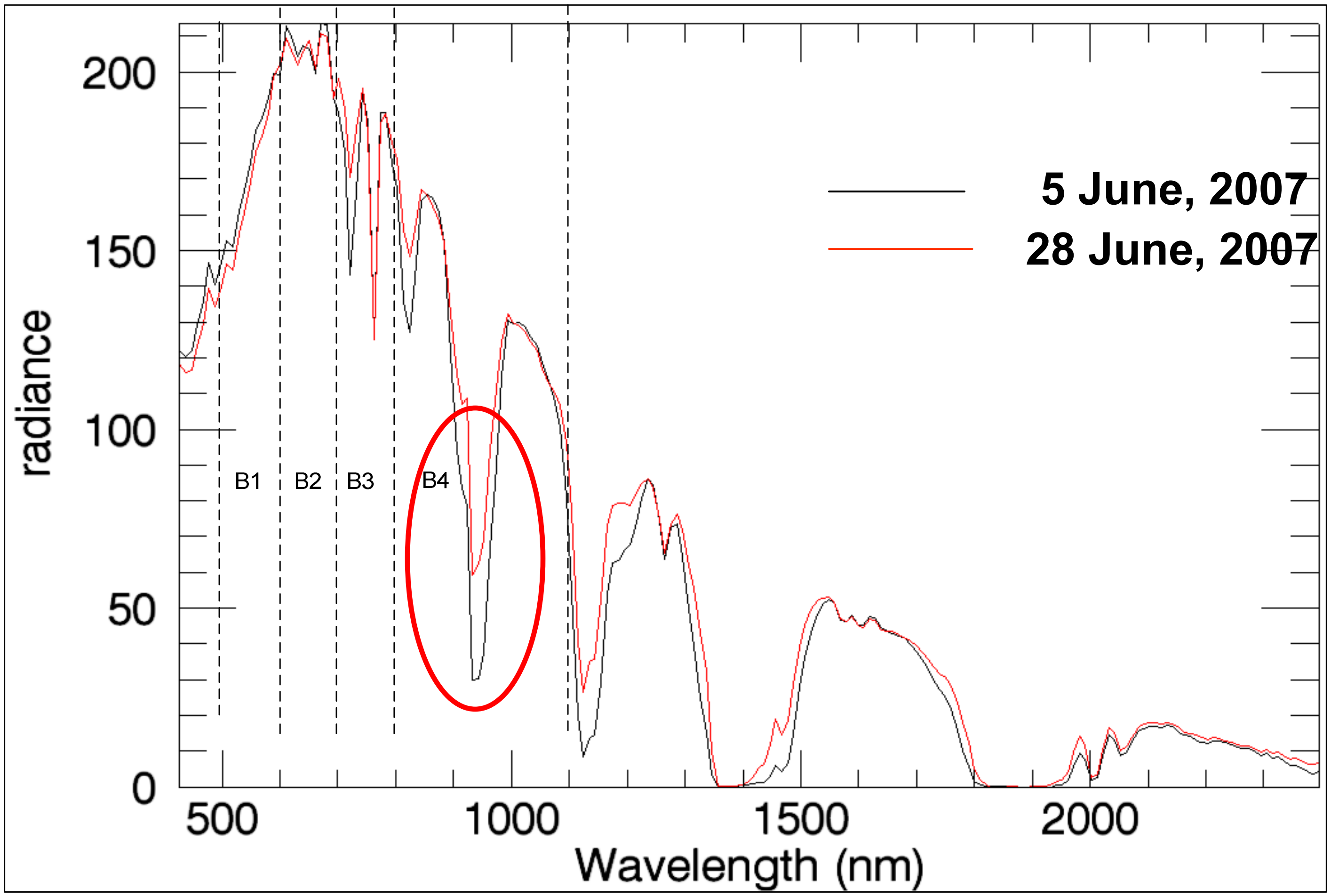
R(λ): Band specific RSR Profile
L(λ): Upwelling Radiance of Target



$$SBAF = \frac{(\int R_{\lambda,MSS} L_{\lambda} d\lambda) / BW_{MSS}}{(\int R_{\lambda,TM} L_{\lambda} d\lambda) / BW_{TM}}$$

Spectral Signature of Libya 4

(MSS Bands indicated)



L5 MSS Band 4 is susceptible to water vapor content in the atmosphere, whereas the corresponding band in L5 TM is not.

Wonderful approach if we know:

Upwelling spectral radiance

function of spectral ground reflectance (i.e. target of interest)

System specific relative spectral response functions

Back in 1993 some young Electrical Engineering Professor at SDSU undertook to write the:

MSS RADIOMETRIC CALIBRATION HANDBOOK

Oct 1993

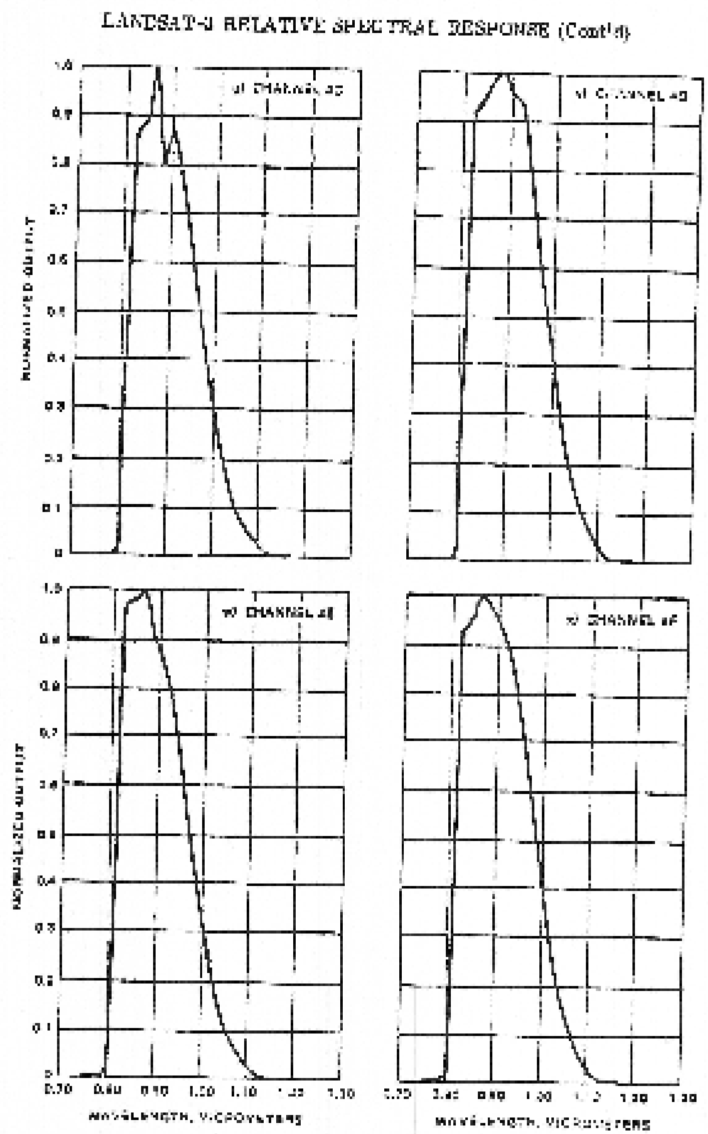
Great book. The plot is a little slow but there is lots of information in words, tables and graphs.

Tough to ‘use’ typed tables and analog graphs

To make a very long story short:

- Book itself was scanned
- Pertinent tables digitized (and corrected)
- Graphs were the big problem:
- Contains about 100 of graphs similar to the following:

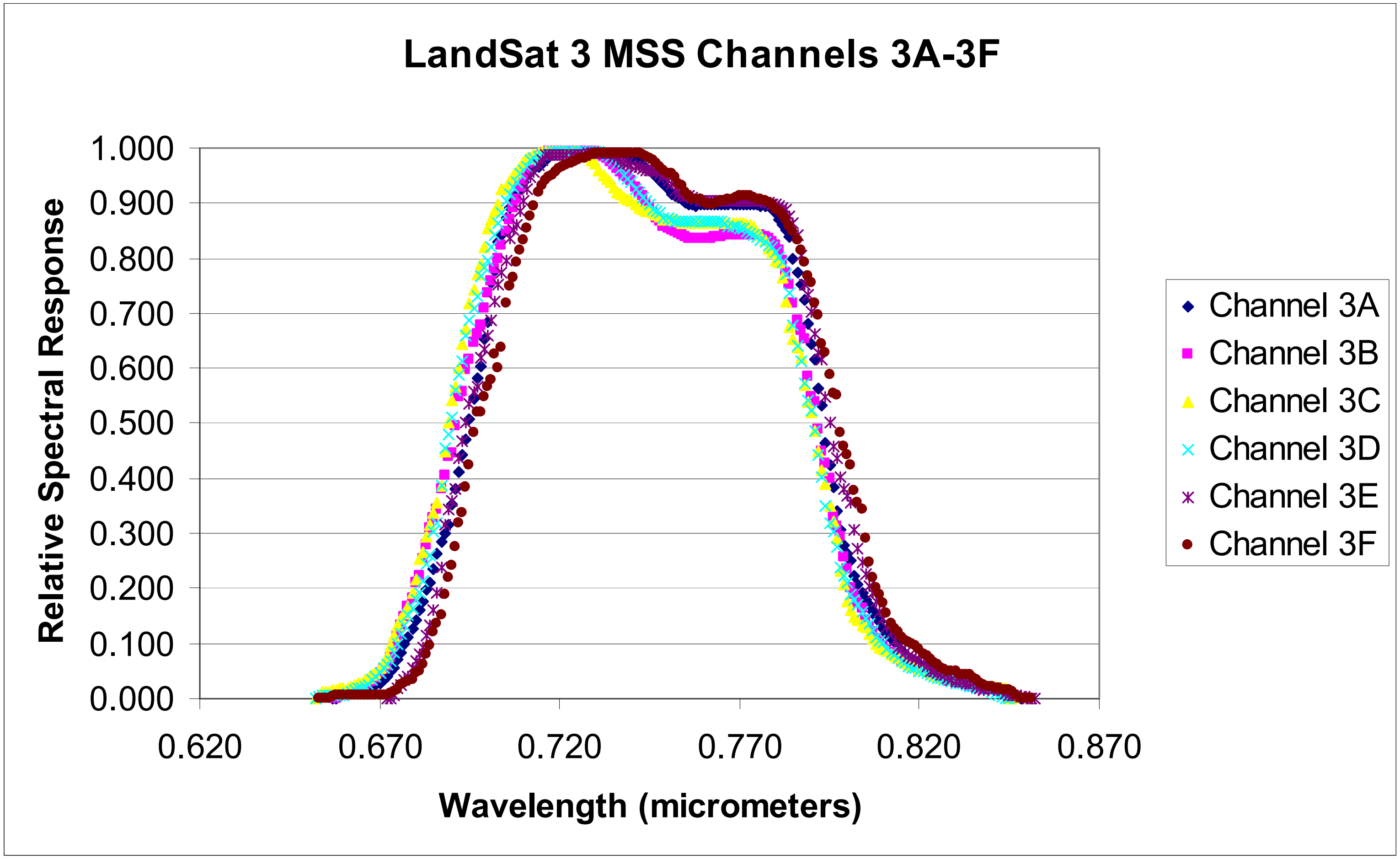
Typical RSR curve set for MSS



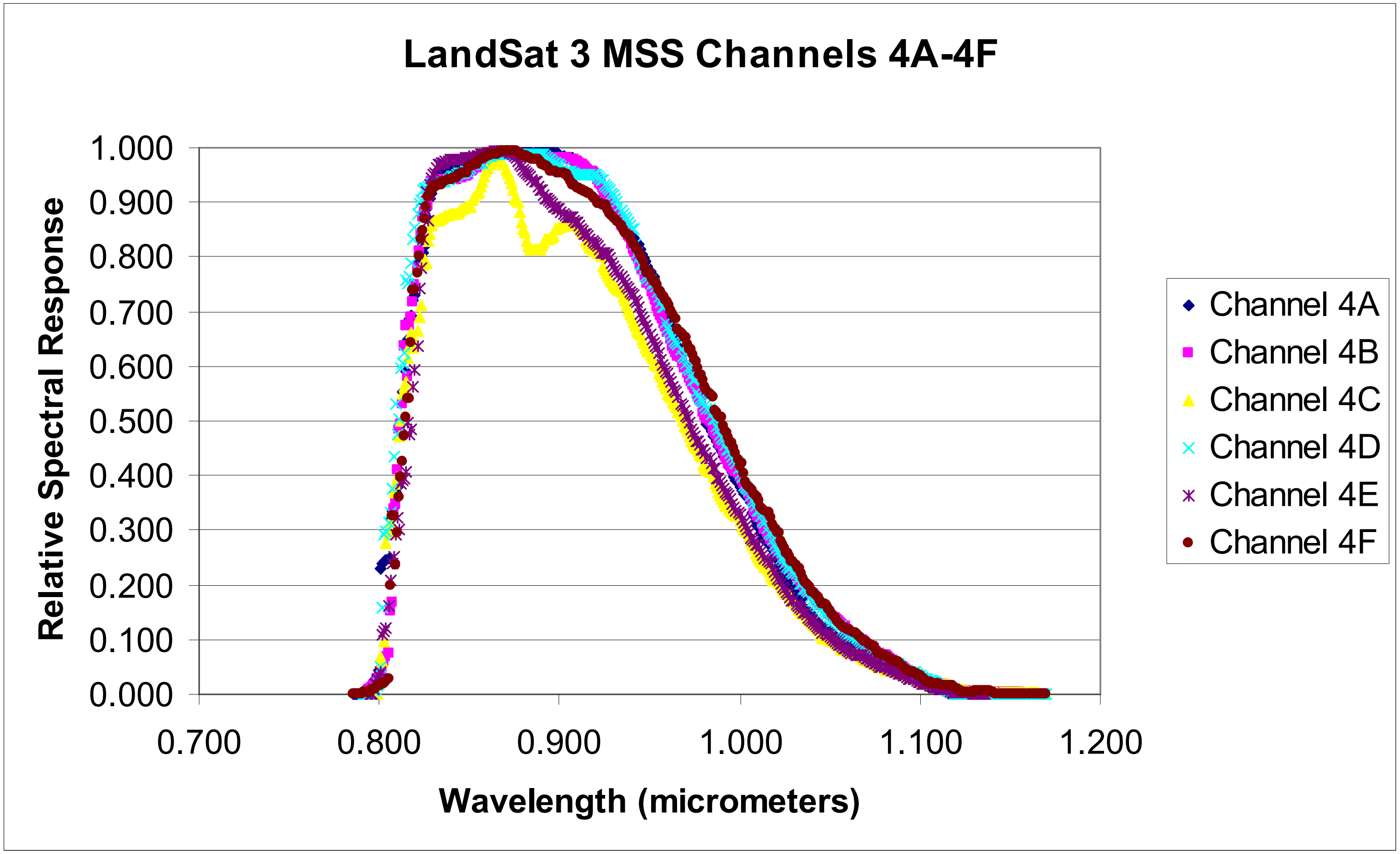
The wonders of a digitization program and an undergraduate:

- Have a complete set of RSR curves for Landsat 1-4 MSS.
  - Still determining how to distribute to the community
- Note that spectral uniformity from detector to detector does present some challenges:

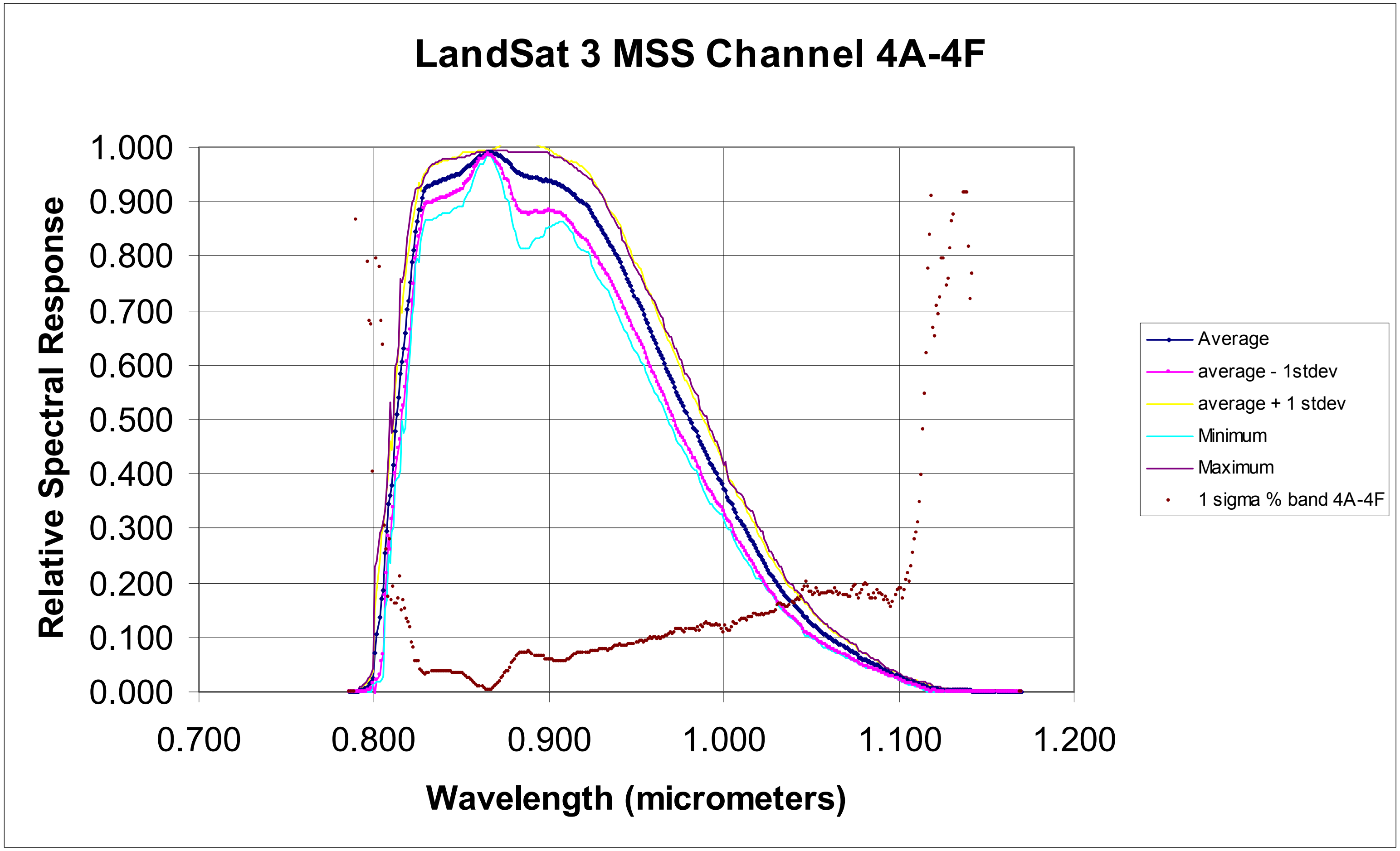
A reasonably consistent set



A bit less consistent set



Same set with statistics



What procedure should a user follow to compare MSS data with newer sensors?

Algorithms are fairly straightforward but will require a bit of a learning curve for many users.

Tutorials?

Workshops?

Monographs?

III. Image Based Atmospheric Correction

Goal to be able to atmospherically correct images in time and location where atmospheric measurements weren’t collected (especially for ‘past events’)

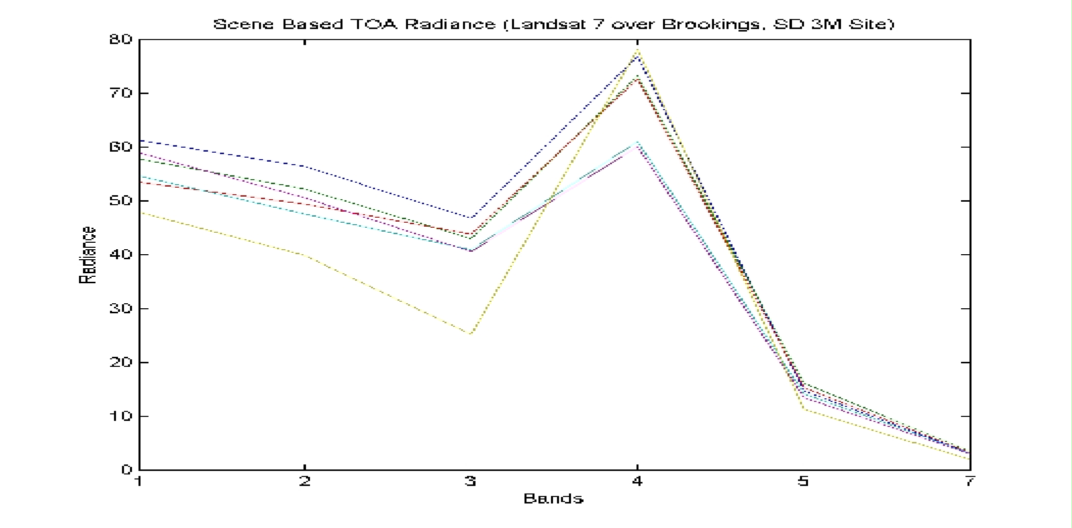
- The scene is corrected based on information on the scene itself.
- Only meant to be a first order correction.
- Model based on a the Bird Model

Image Based ATM Correction

Start with TOA Radiance

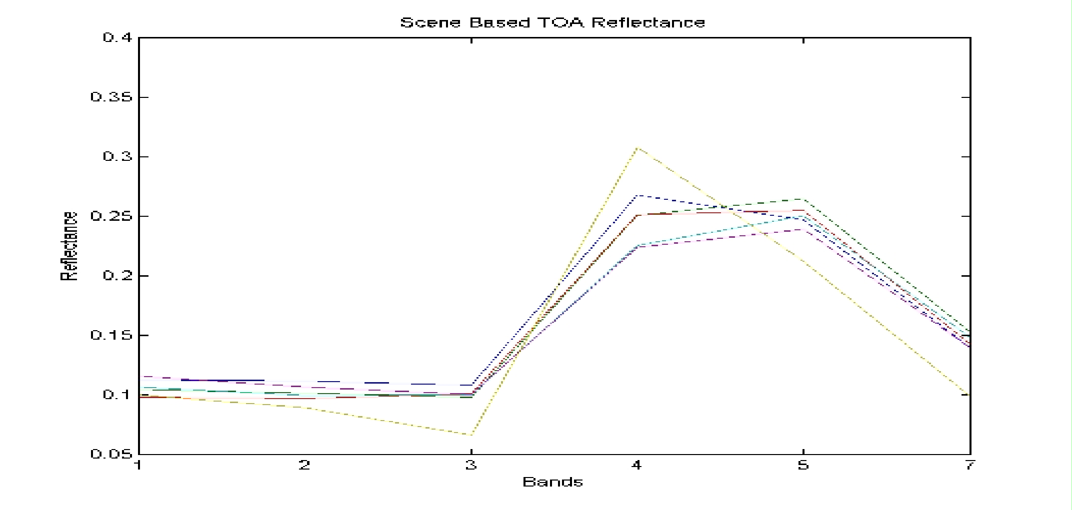
from the image

RadTOA



Convert to TOA reflectance

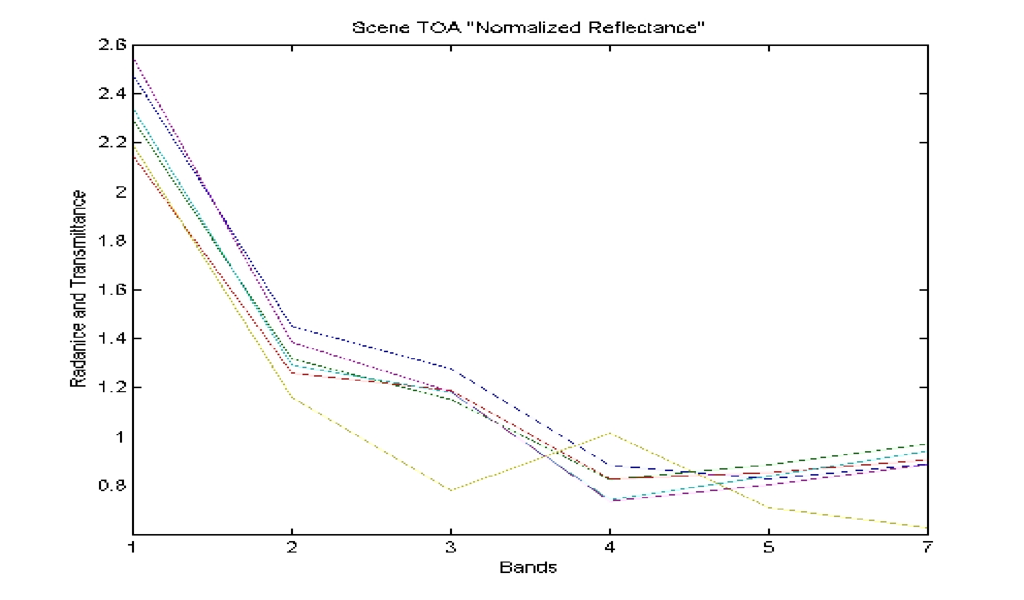
RefTOA



$$refTOA = \frac{RadTOA}{ETR * geo}$$

Image Based ATM Correction

Normalize the data over a multiyear average of the hyperspectral reflectance of the target:
Leaving you with a measure of the transmittance in the longer wavelengths.
From this, work backwards to determine the required aerosol and water vapor to produce the resultant transmittance.

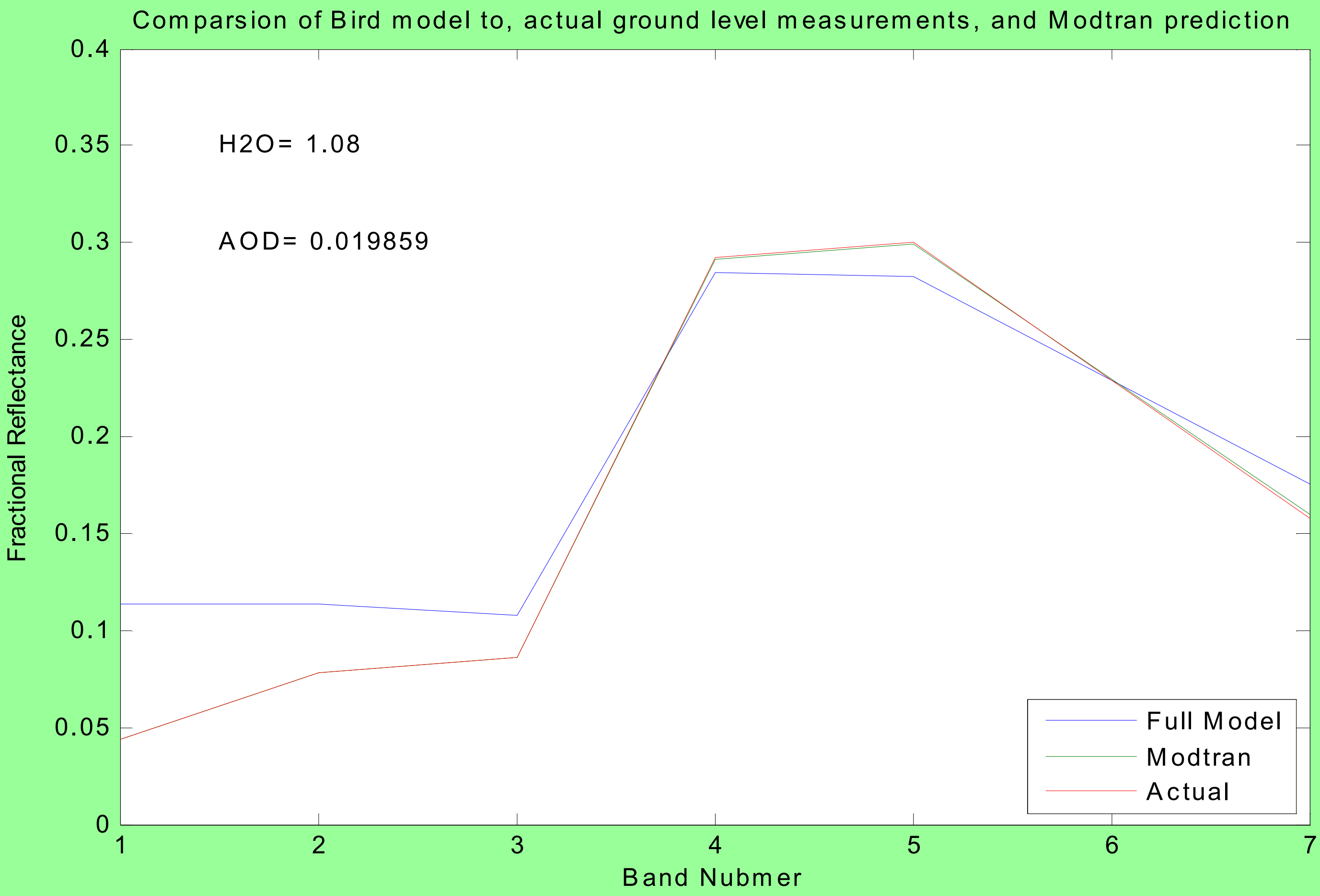


$$NormrefTOA = \frac{TOA}{ETR * geo * \rho_g} = \tau_{\downarrow} * \tau_{\uparrow} \frac{\rho_r}{\rho_g} + \frac{skyshine * \tau_{\uparrow}}{ETR} \frac{\rho_r}{\rho_g} + \frac{Scatter}{ETR * geo * \rho_g}$$

$$NormrefTOA(B5, B7) = \tau_{\downarrow} * \tau_{\uparrow} * \Delta$$

Progress:

Still working on the final atmospheric code, to do the transmittance calculations, but for being an automated script to find and correct for the atmosphere, much promise is being shown.



A Work in Process

Thank you and our continuing appreciating to our sponsors, colleagues, and many collaborators.